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NASA's MOBILE AND TELECOM ANTENNA DEVELOPMENT AT JPL

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Abstract

Chartered by NASA to develop and demonstrate enabling technologies for mobile and satellite telecommunication systems, JPL has developed various antenna technologies throughout the microwave spectrum in the past two decades. The primary driving requirements for these advanced antenna developments are small size, low cost, and low mass. Several antenna types that have been developed to meet these challenges are the omnidirectional low-gain radiator, the electronically steered phased array, the low-profile mechanically steered array, the printed microstrip array, the miniature reflector, the printed reflectarray, and the inflatable structures. Many of these antennas have been field tested and successfully demonstrated.

Introduction

The emerging mobile satellite service systems (Inmarsat, MSAT, Iridium, GlobalSat, ...) will provide data, paging, voice, and video services for a variety of users the world over. To implement these systems, high performance mobile antennas (hand-held or vehicle mounted) are needed to provide an adequate communication link between the satellites (power limited and antenna size limited) and the ground mobile users. Over the past two decades, JPL, under the sponsorship of NASA, has pioneered the development of mobile vehicle antennas for commercial application and spacecraft telecom antennas for deep-space exploration. For the mobile application, the antennas are generally required to be circularly polarized and to provide elevation coverage from 20° above the horizon to zenith and a full 360° azimuth coverage. They have been developed in the frequency ranges of UHF, L-band, S-band, Ku-band, and K/Ka-band. For the deep space telecom application, the antennas required are always of the pencil beam high-gain type with circular polarization (CP)and operating frequencies in the S, X and Ka bands. This paper reviews the designs and developments of these antennas.

Omni-Directional Antennas

The purpose of developing omni-directional antennas is to provide users with antennas that are simple, reliable, and low cost. A low-gain antenna, due to its broad beam, can provide satellite communication regardless of the user's location, orientation, and motion. However, a low-gain antenna may not have enough gain to provide adequate system link margin, especially for higher altitude satellites. In addition, it can easily suffer from multipath signaldegradation due to its broad beamwidth.

At JPL, UHF and L-band circularly polarized omni antennas of the crossed droopingdipole, quadrifilar helix, and microstrip design types have been developed [1]. The elevation coverage of the crossed drooping-dipole antenna can be optimized by varying the separation between its radiating dipoles and the ground plane. The quadrifilar helix, though it suffers from tall physical height, can provide good CP radiation in the low elevation angular region. The low profile microstrip patch can be excited at fundamental or higher-order modes [2] to optimize its elevation coverage.

Directive-Beam Antennas

Medium gain (8 to 20 dB) and high gain (above 20 dB) antennas were developed to provide: (1) adequate system link margin for higher-altitude satellites, higher data rate signals, and higher-frequency operation, and (2) sufficient inter-satellite isolation in the already crowded orbital space and minimum multipath effect. However, in addition to its larger size, a medium-or high-gain antenna generally suffers from high cost due to its needed satellite tracking and steering mechanisms. Two classes of steerable antennas are the electronically steered phased arrays and the mechanical] y steered antennas. These are separately discussed below:

1. L-band phased array antennas: For mobile satellite communication, phased arrays were developed to offer

the advantages of low-profile and conformal countability, aesthetic appearance, and beam agility (for multiple-satellite beam switching). However, these antennas are well known for their complexity and high cost. Two CP phased array antennas [3], shown in Fig. 1, were separately developed by Ball Aerospace corporation [4] and Teledyne Ryan Electronics [5] through contracts and technical guidance by JPL. Both antennas, intended for land vehicle application, use 19 radiating elements with 3-bit diode phase shifters, and both have a diameter of approximately 53 cm with a thickness of 2.5 cm. Satellite tracking is achieved in azimuth by the sequential lobing technique and in elevation by a slow amplitude search mechanism. The tracking mechanism of both antennas is augmented by an open-loop angular rate sensor to combat short signal drop-outs or fades. Currently, a similar version of Ball's antenna system is being installed on Boeing commercial aircraft for satellite communication through the Inmarsat system.

2. L-band mechanically steered antennas: Mechanically steered antennas were developed to provide an option with considerably lower cost than that of phased arrays. The challenge here is to achieve low physical profile. Two types of mechanically steered L-band antenna were developed at JPL. One was a 1X4 tilted microstrip array [6] where a fan beam is generated. The broad fan beam provided complete elevation coverage, while a monopulse system enables the narrow azimuth beam to track the satellite. This antenna has a diameter of 53 cm and a height of 15 cm. The second antenna is a low-profile microstrip Yagi array [7] as shown in Fig. 2 where an array of 16 microstrip patches form four 4-element Yagi arrays. Each Yagi column consists of a single driven patch, a parasitic reflector patch, and two parasitic director patches. The driven patch is excited at two orthogonal feed points (to provide CP) with 115° phase differential, rather than the traditional 90° phase differential. With only one patch per Yagi column requiring direct RF connection, the complexity of the feed circuitry and thus the insertion loss is substantially reduced, and hence the array efficiency is optimized, The overall antenna has a diameter of 53 cm and a height of 3.8 cm (include radome and tracking mechanism).

3. S-band DBSR antenna: Direct Broadcast Satellite Radio (DBSR) system will modulate AM and FM radio signals onto an S-band carrier and transmit to a vast set of users via a geostationary satellite. One of the antennas considered for mounting on a briefcase-sized indoor fixed terminal is a 4-clement microstrip array. This array, shown in Fig. 3, uses the sequential rotation technique [8] to achieve a very robust CP performance. It has a size of 20 cm x 20 cm x 0.3 cm with a gain of 12 dB and 130 MHz bandwidth.

4. Ku-band DBS antenna: The DBS television service is to be brought into the recreational vehicle (RV) market by installing a Ku-band reflector antenna on the rooftop of the vehicle. The reflector antenna, shown in Fig, 4, is to be mechanically steered in both the elevation and azimuth directions to track the satellite. The reflector antenna, being elliptical in shape with an elliptical feed horn, has a radome size of 76 cm in diameter and 40 cm in height. It provides a peak gain of 33.7 dB.

5. K/Ka-band mechanically steered antennas: The more recent developments at JPL are three antennas designed for 20/30 GHz communication experiments using NASA's Advanced Communications Technology Satellite (ACTS) in a JPL program titled the ACTS Mobile Terminal (AMT). The benefits of K/Ka-band, compared to lower frequencies, such as L-band, include a much larger available bandwidth, a higher antenna gain, and/or a substantially reduced antenna size. Reaping these benefits requires overcoming the disadvantages of higher RF component losses, significant rain and foliage attenuations, greater Doppler offset, and the need for a more accurate satellite-tracking system to accommodate a narrower antenna beam. One antenna developed is a mechanical] y steered (azimuth on] y) offset-fed elliptical reflector [9] shown in Fig. 5. This antenna, using more traditional technologies, achieved a peak gain on the order of 22 dB with an overall size of 23 cm in diameter and 10 cm in height. The second antenna is a mechanically steered (azimuth only) low-profile active array [10] using state-of-the-art MMIC technology and multilayer microstrip/stripline design. This antenna, shown in Fig. 6, uses electromagnetically coupled slots and dipoles with a shared receive/transmit (20/30 GHz) aperture. MMIC LNAs and HPAs are incorporated into subarrays of the antenna to achieve better efficiency. The third antenna shown in Fig. 7 is a mechanically steered (elevation and azimuth) slotted waveguide array [11] developed for aeronautical satcom application. The antenna, developed by EMS Technologies, Inc. under contract with JPL, achieved a transmit gain of 30 dB and a receive G/T of O dB/K.

6. Current satcom antenna developments: Two types of antennas, currently being developed at JPL for future spacecraft and mobile satcom applications, are the microstrip reflectarray and the inflatable planar array. A

0.5m Ka-band microstrip reflectarray [12], shown in Fig. 8, has recently been developed, Its lower mass and smaller size lend themself to future building-wall-mounted or mobile-rooftop-mounted satcom antenna applications, as well as future microspacecraft telecom antennas. A further mass-reduced 1 m X-band inflatable microstrip reflectarray is currently being developed for future deep-space telecom application. The second type low-mass antenna being developed is an L-band inflatable planar array [13]. The concept is shown in Fig. 9. It is a multilayer, aperture coupled, dual-polarized microstrip array design with one-dimensional electronic beam scanning capability and has an aperture size of 3 m by 1 m. These inflatable antenna structures, although being developed for spacecraft application, do have the potential for future military ground force usage.

Conclusion

The above antenna developments have successfully demonstrated one of the critical technologies in accessing our future wireless information superhighway on land, in air, and in space.

Acknowledgment: The research described in this paper was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

References:

1. K. Woo, et al., "Performance of a family of omni and steered antennas for mobile satellite applications," International Mobile Satellite Conference, Ottawa, Canada, June 1990, pp. 540-544.

2. J. Huang, "Circularly polarized conical patterns from circular microstrip antennas," IEEE Trans. Antennas Propag., vol. AP-32, Sept. 1984, pp. 991-994.

3. J. Huang, "L-band phased array antennas for mobile satellite communications," IEEE Vehicular Tech. Conference, June 1987, pp. 113-117.

4. F. Schmidt, et al., "MSAT Final Report," Ball Aerospace, JPL contract no. 957467, 1988.

5. S. Y. Peng, et al., "Final Report, vehicle antenna for the mobile satellite experiment," Teledyne Ryan Electronics, JPL contract no. 957468, 1988.

6. V. Jamnejad, "A mechanically steered monopulse tracking antenna for PiFEx," JPL MSAT-X Quarterly, no. 13, 1988, pp. 18-27.

7. J. Huang and A. Densmore, "Microstrip Yagi array antenna for mobile satellite vehicle application," IEEE Trans. Antennas Propag., vol. AP-39, July 1991, pp. 1024-1030.

8. T. Teshirogi, et al., 'Wideband circularly polarized array with sequential rotation and phase shift of elements," International ISAP symposium, Japan, August 1985, pp. 117-120.

9, A. Densmore and V. Jamnejad, "A satellite-tracking K and Ka-band mobile vehicle antenna system," IEEE Trans. Vehicle Tech., vol. VT-42, Nov. 1993, pp. 502-513.

10. A. Tulintseff, "Series-fed-type linear arrays of dipole and slot elements transversely coupled to a microstrip line," IEEE AP-S/URSI symposium, July 1993, pp. 128-131.

11. A. Densmore and M. Guler, "An aeronautical-mobile 20/30 Ghz satellite-tracking antenna for high data rate satcom," IEEE AP-S/URSI symposium, July 1996, pp. 1108-1111.

12. J. Huang, "A high-gain circularly polarized Ka-band microstrip reflectarray," Microwave and Optical Technology Letters, vol. 14, Feb. 1997, pp. 163-166

13. J. Huang, et al., "Super-low-mass spaceborne SAR array concepts," IEEE AP-S/URSI symposium, Montreal, Canada, to be published, July 1997

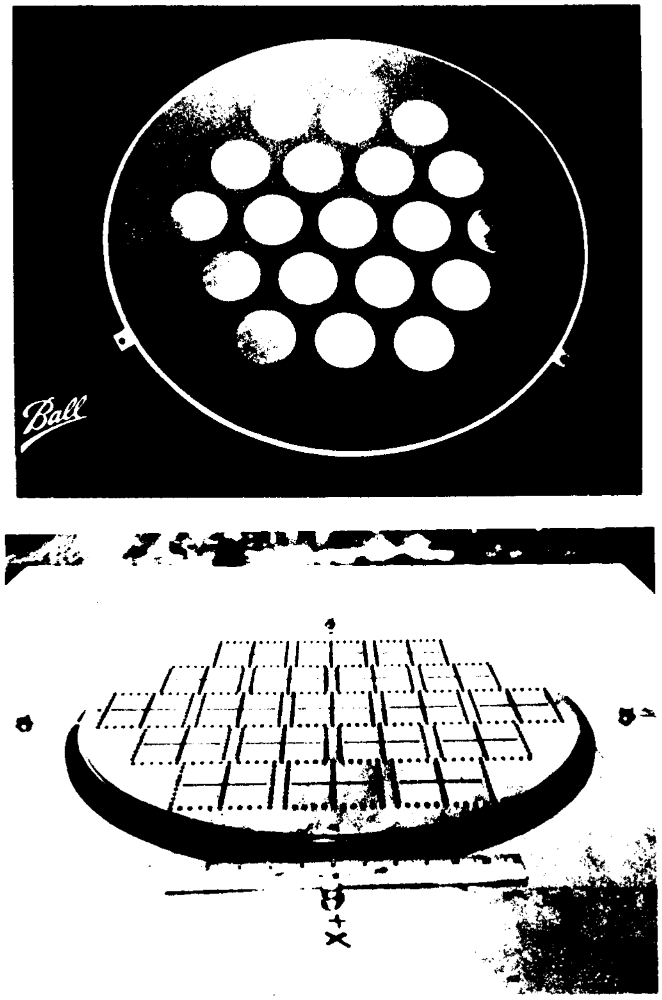

Figure 1. L-band mobile **phased array antennas, Ball design (top) and Teledyne** design (bottom).

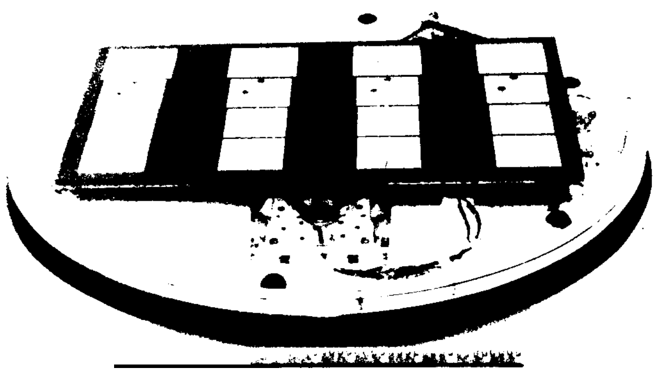

Figure 2. L-band mechanically steered **microstrip** Yagi array antenna.

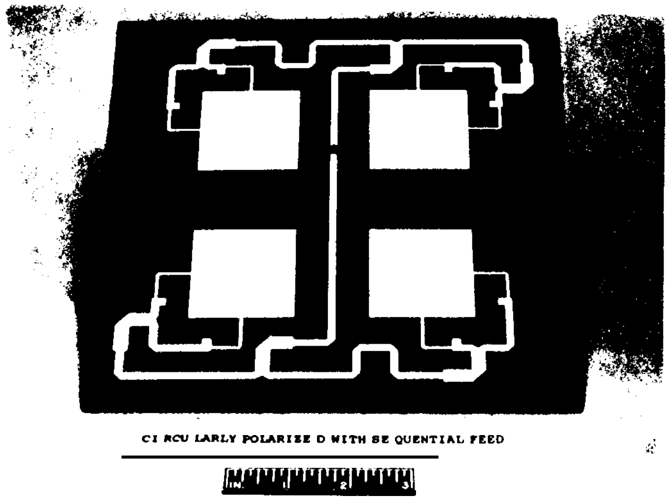

Figure 3. S-band **microstrip** array for DBSR application.

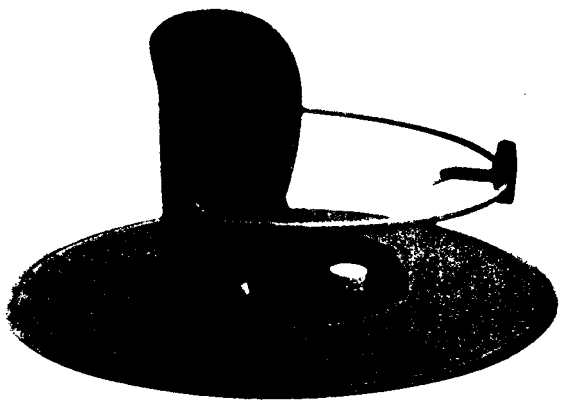

Figure 4. Ku-band mechanically steered DBS reflector antenna for large land vehicles.

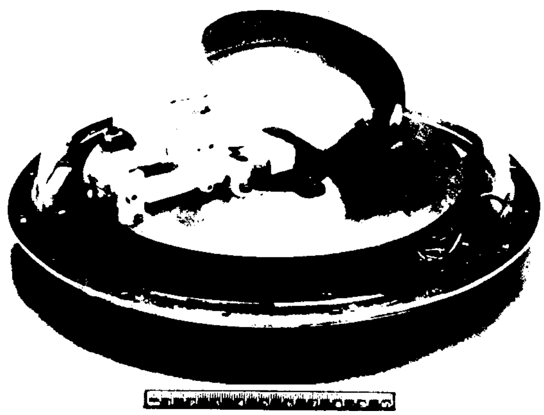

Figure 5. **K/Ka-band** mechanically steered elliptical **reflector** antenna.

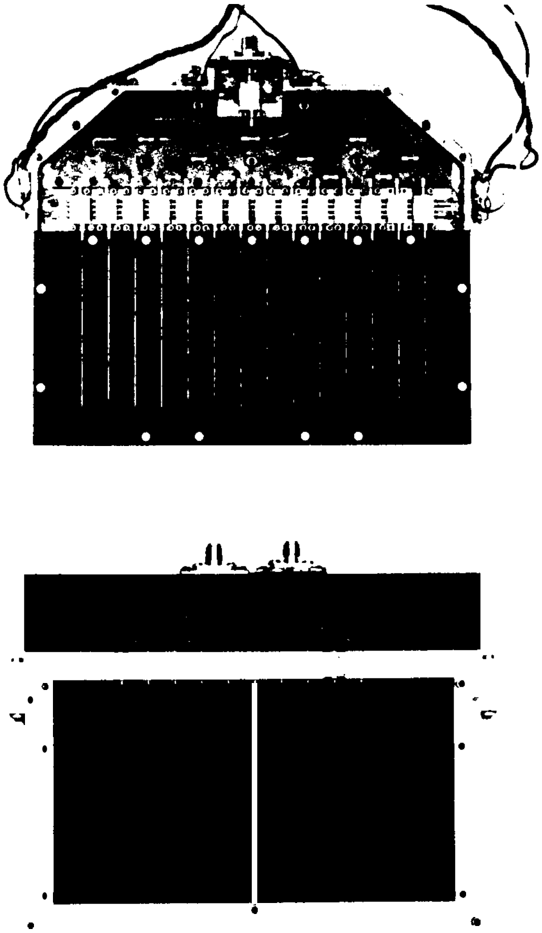

Figure 6. **K/Ka-band** mechanically steered active array with MMIC components.

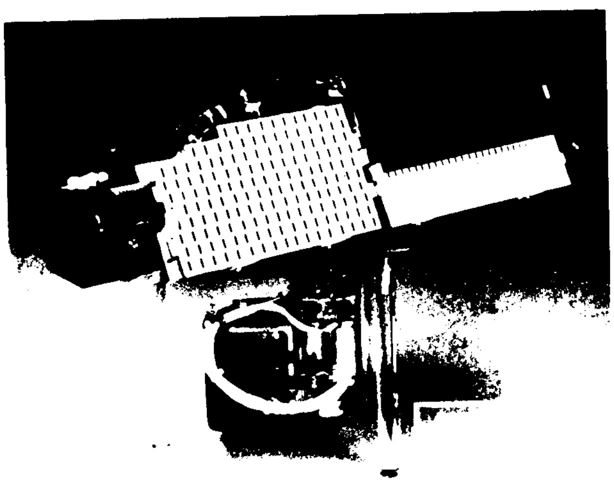

Figure 7. **K/Ka-band** mechanically **steered slotted-**waveguide array for aeronautical application.

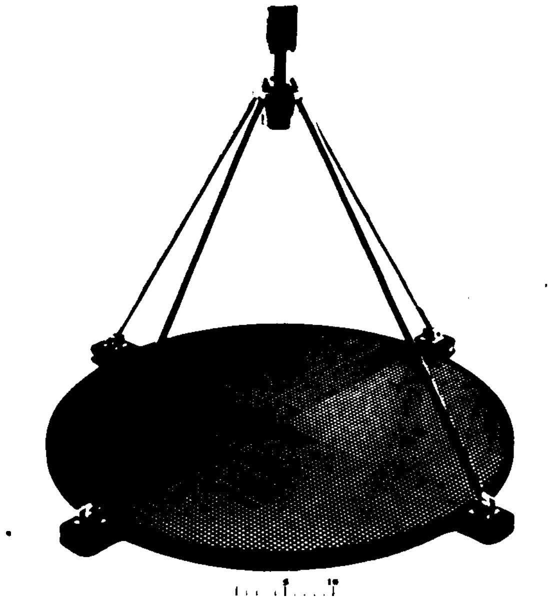

Figure 8. **Ka-band** 0.5m microstrip **reflectarray** with 6,924 elements.

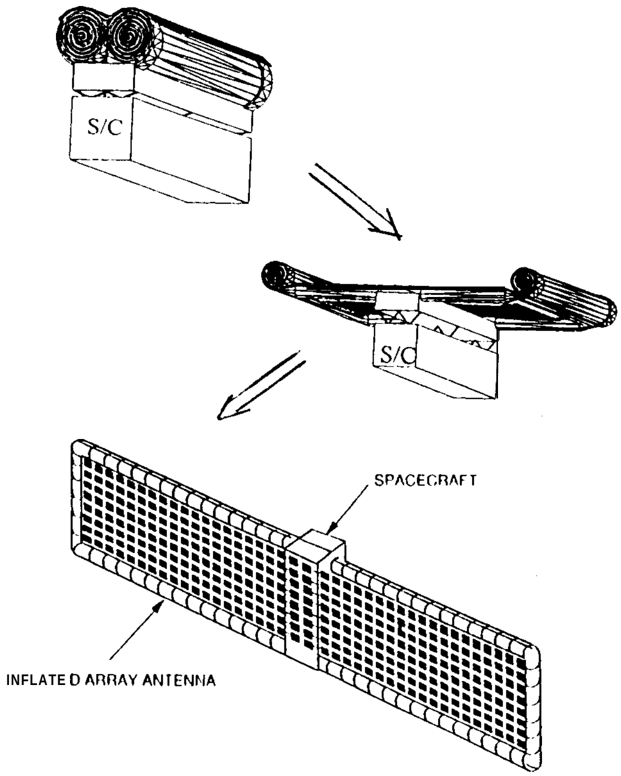

Figure 9. L-band 10m x 3m inflatable planar **microstrip** array.